

# Bread Quality of Spelt Wheat and Its Starch<sup>1</sup>

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## ABSTRACT

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Flours from five spelt cultivars grown over three years were evaluated as to their breadbaking quality and isolated starch properties. The starch properties included amylose contents, gelatinization temperatures (differential scanning calorimetry), granule size distributions, and pasting properties. Milled flour showed highly variable protein content and was higher than hard winter wheat, with short dough-mix times indicating weak gluten. High protein cultivars gave good crumb scores, some of which surpassed the HRW baking control. Loaf volume was correlated to protein and all spelt cultivars were at least 9–51% lower than the HRW control. Isolated starch properties revealed an increase in amylose in the spelt

starches of 2–21% over the hard red winter wheat (HRW) control. Negative correlations were observed for the large A-type granules to bread crumb score, amylose level, and final pasting viscosity for cultivars grown in year 1999 and to pasting temperature in 1998 samples. Positive correlations were found for the small B- and C-type granules relative to crumb score, loaf volume, amylose, and RVA final pasting viscosity for cultivars grown in 1999, and to RVA pasting temperature for samples grown in 1998. The environmental impact on spelt properties seemed to have a greater effect than genetic control.

U.S. production of spelts peaked in the early 1900's and declined steadily thereafter. The first recorded U.S. production of spelt occurred in North and South Dakota, Kansas, Nebraska, and Minnesota. Limited production also occurred in Wisconsin, Michigan, Iowa, Illinois, Indiana, Montana, Wyoming, and Texas (Stallknecht et al 1997). The inconsistent yield potential, even with the higher protein advantage of spelt, could not compete with the progress of breeding programs giving improved yields and quality for barley, oats, and the free-threshing wheats. This, in addition to the unavailability of adapted cultivars, low test weights, and the time and expense of dehulling contributed to the loss of interest in the ancient wheats. Today, limited spelt production in the U.S. occurs in Pennsylvania, Michigan, Indiana, Kansas, and North Dakota, with the major production centering in the midwest, especially Ohio (Stallknecht et al 1997).

Environmental conditions, particularly growing-season and precipitation, significantly affect the yield competitiveness of spelt. Winter spelt often outyields spring oats and barley when early growing season temperatures are cold and moisture is limited. In Montana, in regions with low growing season precipitation, some cattle producers plant spelt in preference to spring oats due to the yield advantage of the winter spelt. Studies conducted in Germany indicate that the hull of spelt provides an advantage to the seed germination (Ruegger et al 1990a) and provides protection against soilborne pathogens in conditions unfavorable to germination (Riesen et al 1986).

Research on the nutritional aspects of spelt reports a wide variability in the chemical constituents of spelt wheats. Ranhotra et al (1995) showed few differences between hard red wheat cultivars and Canadian spelt selections. These grains were evaluated for gluten traits, chemical composition, amino acid composition, and protein dietary value. The data did suggest possible validity of the claim that spelt may be easier for humans to digest than wheat.

Other studies have reported variations in protein, lysine, vitamins, crude fat, minerals, and gliadin-to-glutenin ratios among spelt selections (Abdel-Aal et al 1995; Ranhotra et al 1995, 1996a; Kasarda and D'Ovidio 1999). An environmental study concerning spelt and hard red wheat cultivars, grown in five locations showed all the spelt cultivars had consistently higher (18–40%) protein content than hard red winter wheat (Ranhotra et al 1996b). This same study also indicated lower lysine content in spelt compared with hard red winter wheat, which was inversely related to percent protein. These results indicate that variations in the protein content of the grain for a given species is highly dependent on cropping practices and environmental conditions (Clamot 1984).

Spelt is the only husked wheat that is currently grown in the United States for human food consumption. From 1987, market promotions for human consumption increased from <40 ha to >3,200 ha. Spelt products are available through health food outlets as grain, whole grain flours, white flours, and processed products. These products include assorted pasta, cold and hot cereals, and prepackaged bread, muffin, and pancake mixes (Stallknecht et al 1996). Hucl et al (1995) reported positive results with spelt flours treated with oxidants; they produced loaf volumes similar to bread wheat. In Europe, spelt harvested in the hard dough stage and roasted is called "grunkern" and is considered a gourmet food to be used in breads, cereal, soups, and casseroles. Thus, spelt in the United States remains a commodity in the health food and specialty markets, with limited crop production. While the gluten fraction of spelts has received most of the attention with respect to its possible unique products and functionality, the starch fraction has received little attention.

Preliminary work (Abdel-Aal et al 1999a) revealed lower starch yields from spelts vs. common wheats, as well as lower amylose content, higher lipid levels, and little difference in starch size distributions. Another study revealed a wide range of gelatinization onset temperatures for spelts compared with other wheat starches, while  $\Delta H$  of spelts were very similar to that of common wheat starches. Abdel-Aal et al (1999c) also reported spelts had lower amylose content (Concanavalin-A method, Megazyme assay kit) and  $\alpha$ -amylase digestibility of ungelatinized soft-spelt starch occurred at a higher rate than common wheat starches.

The present study assesses the composition and properties of flour and starch from five spelt cultivars grown in the same location over 1997, 1998, and 1999 growing seasons. Starch fractions within each flour are characterized with regard to chemical attributes, granule size content, gelatinization properties, and pasting properties. This study may help elucidate some unique characteristics of spelt flour and starch for future uses in the food industry, as well as provide additional information on environmental effects on starch granule size distribution and molecular structure.

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## MATERIALS AND METHODS

### Materials

Five hard winter spelt cultivars (Oberkulmer Rotcorn, Rouquin, Brute, Lobo, and Sammy) grown in 1997, 1998, and 1999 in central Ohio were obtained from the Spelt Yield Trial Nursery, Wooster, OH. The growth habits of spelt are similar to those of winter wheat (Ohio Cooperative Extension Service 1987). The control flour was a 1999 hard red winter blend regional baking standard (RBS) obtained from the U.S. Grain Marketing Production Research Center, Manhattan, KS. Spelt wheat was dehulled using rubber-covered rollers and the hulls are aspirated away. They were then tempered to  $\approx 16\%$  moisture and 300–500 g (dependent on quantity received) were milled on C.W. Brabender Quadramat Sr. mill at the U.S. Grain Marketing Production Research Center, Manhattan, KS. The mill products of bran, shorts, break flours, and red dog were collected and weighed.

### Physical and Chemical Tests

Moisture was determined in samples oven-dried for 1 hr at  $130^{\circ}\text{C}$  (Approved Method 44-15; AACC International 2000) and protein by Dumas combustion method (Leco Corp., St. Joseph, MI). Amylose was measured after precipitation of the amylopectin concanavalin-A complex (Megazyme amylose-amylopectin assay kit, Wicklow, Ireland). Starch damage was measured by the method of Gibson et al (1993) (starch damage assay kit from Megazyme); and total starch by enzyme digestion (total starch kit from Megazyme). Total  $\alpha$ -amylase activity was measured in isolated starches with a test kit (Ceralpha  $\alpha$ -amylase kit, Megazyme). Swelling powers of some flours were determined at  $92^{\circ}\text{C}$  by a slight modification of the method of Crosbie et al (1992). In the modified method, the hot paste was centrifuged soon after heating instead of cooling the paste and then centrifuging. Test weight was the weight per Winchester bushel, determined by Approved Method 55-10 (AACC International 2000) and expressed to the nearest tenth of a pound. Thousand kernel weight, done on a Count-A-Pak Syntrol seed counter (Seedburo Equipment Company, Chicago, IL) was the weight (g) of 1,000 kernels of wheat of a 40-g sample from which all foreign material and broken kernels had been removed. Single kernel hardness was determined by AACC Approved Method 55-31 on the Single Kernel Characterization System 4100 (Perten Instruments, Reno, NV.) All tests were replicated at least in duplicate and the means were analyzed using Fisher's LSD from SAS software.

### Starch Isolation

Starch was examined for size distribution analysis and isolated using the method of Bechtel and Wilson (2000), giving a starch recovery of 81–85%. This isolation procedure gives a more complete recovery of starch granules for size distribution analysis but does leave residual traces of proteases with the starch granules and should not be used for any chemical analysis. Starch for all chemical analysis was isolated from the flour by a method similar to Reddy and Seib (1999) and that starch was used for all other testing. Flour (20 g) was added to 0.02M HCL (200 mL) at  $4^{\circ}\text{C}$  and the mixture was held for 8–10 min. Sodium metabisulphite (0.5%, based on wheat) and thiomersal (0.01%) were added to the slurry and buffered to pH 7.6 (0.09M) by the addition of tris(hydroxymethyl)aminomethane (2.5 g) followed by adjustment with 1M HCL. Protease (type XIV, Sigma Chemical, 0.5%, based on wheat) was dissolved in 0.02N HCL (12 mL) and the solution was held for 3–5 min at  $25^{\circ}\text{C}$  to denature  $\alpha$ -amylase that may have been present and then the solution was added to the flour slurry. The mixture was digested at  $4^{\circ}\text{C}$  for 30 hr. The digest was placed atop a 60- $\mu\text{m}$  nylon mesh sieve. The softened mass was rubbed on the sieve and washed with water ( $2 \times 20$  mL). The throughs were collected and centrifuged at  $2,500 \times g$  for 10 min. The overs were placed in a test tube and ground with a homogenizer for 30 sec,

placed on the 60- $\mu\text{m}$  nylon mesh and the throughs and overs were collected. The grinding procedure was repeated twice more and the overs were discarded. All throughs were combined and centrifuged at  $2,500 \times g$  for 10 min. The supernatant was discarded and the sedimented starch was washed with water ( $3 \times 20$  mL), centrifuged, and the dark tailings were removed. The combined starch was then washed with 1% sodium chloride solution (20 mL) and with water ( $3 \times 10$  mL). The starch was air-dried for a minimum of 48 hr. The isolated starches from the 15 spelt wheats and the RBS control contained  $\approx 13\%$  moisture and 0.2–1.2% protein, more than likely due to residual gluten protein not solubilized during the isolation procedure. Starch recovery averaged  $\approx 79\%$  from flour.

### Starch Granule Size Distribution

The starch granule size analysis was performed on a Lecotrac laser diffraction sizing instrument. The volume % data was adjusted to larger diameters using adjustment factors for spelt wheat as described in Wilson et al (2006).

### Mixograms and Micro-Baking (10 g) of Flour

Mixograms (National Manufacturing, Lincoln, NE) were performed in duplicate on flour according to the procedure of Finney and Shogren (1972). Mixing and water requirements for 10 and 100 g of flour (14% mb) were similar, except that generally less water (1–2 %) was required for 10 g of flour (Shogren and Finney 1984).

Due to the limited amount of flour that was available for this study, micro-bakes were in duplicate on 10 g of flour (Shogren and Finney 1984). The baking was conducted in the Hard Winter Wheat Quality Bake Lab of the U.S. Grain Marketing and Production Research Center, USDA-ARS-NPA, Manhattan, KS. The ingredients in the 100-g pup loaf method were reduced by a factor of 10, instant dry yeast was used, and bromate was replaced with 50 ppm of L-ascorbic acid. Fermentation was done for 120 min followed by molding on a specialty mold, proofing  $57 \pm 2$  min, and then baking for 13 min at  $232^{\circ}\text{C}$ . Loaf volume was measured in a volumeter and standardized by means of one or more blocks that had volumes within the range of the experimental loaves. Crumb grain and color was visually evaluated by the lead baker and digital images of the sliced loaves were collected for support of the visual evaluation.

### Differential Scanning Calorimetry (DSC)

DSC measurements were obtained with a Pyris-1 DSC (Perkin-Elmer, Norwalk, CT). Isolated starch (3.0 mg, dwb) was weighed with a microbalance into large DSC stainless steel pans. Purified deionized distilled water (12  $\mu\text{L}$ ) was added at a starch-to-water ratio of 1:4 and pan was sealed and allowed to stand at least 1 hr for hydration. Samples were held at  $5^{\circ}\text{C}$  for 1 min, then the temperature was raised at  $10^{\circ}\text{C}/\text{min}$  to  $130^{\circ}\text{C}$ . Onset ( $T_o$ ), peak ( $T_p$ ), and conclusion ( $T_c$ ) temperatures with enthalpy ( $\Delta H$ ) of two endotherms were computed automatically; an empty pan was used as a reference.

### Starch Pasting Properties

Pasting properties of the isolated starches were measured on a Rapid Visco-Analyser (Series 4, Newport Scientific, Warriewood, Australia) interfaced with a personal computer equipped with Thermocline and Thermoview software (Newport Scientific). Starch (3.0 g, db) was added to preweighed deionized distilled water in an RVA canister to achieve a total weight of 28 g. The stirring speed was initially 960 rpm for 10 sec followed by a speed of 160 rpm for the remainder of the test. The Standard 1 temperature profile was an initial temperature of  $50^{\circ}\text{C}$  held for 1:00 min, after which it ramped to  $95^{\circ}\text{C}$  to 4:45 min; it was held at  $95^{\circ}\text{C}$  to 7:15 min, and then ramped down to  $50^{\circ}\text{C}$  to 11:00 min; finally it was held at  $50^{\circ}\text{C}$  to a total of 13:00 min.

## RESULTS

### Properties of Spelt Wheat and Milling

Test weights of Oberkulmer Rotkorn, Rouquin, Brute, Lobo, and Sammy cultivars over three growing seasons had a range of 52.0–62.0 lb/bushel and 1,000 kernel weights had a range of 24.7–41.4 g (Table I). Milling yields of all cultivars and years were 62.2–73.1%, with break flours and red-dog being combined in the flour. Single kernel hardness values indicated that all these spelt wheat cultivars were soft, with values of 16.5–39.5 hardness index (HI) over the three years. Hard wheats have single kernel HI of 45–80 compared with 25–35 for soft wheats (Gaines et al 1996).

### Analytical and Bake Properties of Spelt Flour

The protein contents of all five cultivars of spelt wheat grown in 1997 were higher than the RBS control flour, whereas in 1998 and 1999, they were lower in protein content except Oberkulmer Rotkorn 1998 and 1999, which were not significantly different than the control (Table II). All spelt flours, with the exception of Rouquin and Brute 1999 with peak mix times of 6.6 and 11.0 min, respectively, had shorter peak mix times than the RBS control. Loaf volume closely correlated to protein content with the highest loaf volumes resulting from cultivars grown in 1997, and the variability was more pronounced from year to year than cultivar to cultivar. The loaf volumes of all spelt wheats were less than that of the RBS control. Oberkulmer Rotkorn 1997 and 1998,

Rouquin 1997, Brute 1998, Lobo 1997, and Sammy 1999 had crumb scores similar to the RBS control, whereas the remainder of the spelt wheat loaves scored below the control. The higher crumb scores were related mostly to crumb color where the preferred color is creamy, as in the RBS control. Over half of the test loaves had dull or gray-colored crumb, possibly due to low loaf volumes.

### Properties of Spelt Starch

Total starch isolated by protease digestion of all cultivars of flour, including the RBS flour (75–82%) were not significantly different from the control except for the reduced recoveries from Oberkulmer Rotkorn 1998 and 1999 flours. Damaged starch levels were lower in the spelt starches than in the RBS control (4.3%), which more than likely was due to the soft endosperm of all spelt flours. Amylose contents of all spelt starches were 29.8–33.2%, higher than the RBS control (26.1%) (Table III). The temperatures and enthalpies of gelatinization at ≈80% MC for Rouquin 1999; Brute 1998, 1999; Lobo 1999; and Sammy 1997, 1998, and 1999 starches showed significant elevation of  $T_o$  of 2.4–5.2°C over that of the RBS control. But  $T_p$ ,  $T_c$ , and enthalpy values were not significantly different from those of the RBS control (Table IV). Temperatures and enthalpies of dissociation of the amylose/lipid complex showed a significant elevation of  $T_o$  of Oberkulmer Rotkorn 1997, 1998, 1999; Rouquin 1997, 1998; Brute 1997; and Sammy 1997, 1998, 1999.  $T_p$  was elevated for

TABLE I  
Grain Properties and Yields of Straight-Grade Flour<sup>a</sup>

Cultivar	Year	Bushel Wt (lb)	1000 Kernel Wt (g)	Single Kernel Hardness Index	Flour Yield (%)
Oberkulmer Rotkorn	1997	56.0	39.9	21.5	70.2
	1998	58.4	41.4	17.2	73.1
	1999	55.6	36.0	16.5	68.8
Rouquin	1997	52.0	26.5	24.8	63.9
	1998	60.4	34.9	21.6	70.0
	1999	59.2	36.4	20.5	69.6
Brute	1997	58.4	34.3	30.3	67.0
	1998	60.8	36.5	21.1	70.1
	1999	60.8	37.0	22.3	69.1
Lobo	1997	58.0	37.6	17.4	62.2
	1998	62.0	40.0	13.4	70.5
	1999	61.2	39.2	33.5	69.5
Sammy	1997	56.8	24.7	39.5	68.1
	1998	61.2	40.5	28.2	72.7
	1999	60.4	39.5	34.6	68.2

<sup>a</sup> All samples were ranked soft, except 1997 Sammy, which was mixed.

TABLE II  
Analytical and Bake Properties of Spelt Flour<sup>a</sup>

Cultivar	Year	Moisture (%)	Ash (%)	Protein (%)	Abs (14%) (%)	Bake MT (min)	Crumb Score	LV (cm <sup>3</sup> )	Crumb Color
Oberkulmer Rotkorn	1997	11.0	0.5	12.4a*	56.5	2.5b*	4.3a	72a*	Cream
	1998	10.3	0.6	11.7ab	55.5	2.5b*	4.0ab	63b*	Cream
	1999	11.4	0.5	10.5b	57.7	3.5a*	3.3b*	56b*	Dull
Rouquin	1997	11.2	0.5	12.4a*	55.3	2.3c*	4.2a	70a*	Cream
	1998	10.5	0.5	9.3b*	52.8	2.7b*	1.6b*	52b*	Dull
	1999	11.6	0.4	8.7b*	56.7	6.6a*	0.5b*	42c*	Gray
Brute	1997	10.6	0.5	11.5a	62.2	3.1b*	3.5b*	77a*	Cream
	1998	10.4	0.6	9.9b*	57.7	3.6b*	4.1a	64b*	Cream
	1999	11.5	0.4	9.5b*	58.7	11.0a*	1.9c*	50c*	Dull
Lobo	1997	10.9	0.5	12.8a*	60.7	2.6b*	4.8a	72a*	Cream
	1998	10.0	0.5	10.2b*	56.7	2.8b*	1.9b*	58b*	Dull
	1999	11.4	0.4	9.4b*	58.5	4.9a*	3.4ab*	51b*	Dull
Sammy	1997	11.2	0.5	12.9a*	54.4	2.3c*	2.2ab*	65a*	Dull
	1998	10.2	0.5	9.4b*	54.7	2.5b*	1.5b*	53b*	Dull
	1999	10.2	0.4	9.7b*	58.7	4.4a*	3.5a	56b*	Dull
RBS		11.2	0.5	11.3	61.1	5.5	4.3	85	Cream

<sup>a</sup> Means in the same column followed by different letters indicate significant differences ( $P \leq 0.05$ ); \*, indicates a significant difference ( $P \leq 0.05$ ) from the control flour, a 1999 regional baking standard (RBS) obtained from the U.S. Grain Marketing Production Research Center, Manhattan, KS.

Oberkulmer Rotkorn 1997, 1998, 1999; Brute 1997, 1998, 1999; Lobo 1998; and Sammy 1997, 1998, 1999; and Rouquin 1997, 1998, 1999. Brute 1997, 1999 showed a slight elevation of melting enthalpy over that of the RBS control.

### Granule Size Distribution

To evaluate differences in starch size distributions and effects on other properties, the granule size distribution was represented according to diameter vs. volume % using two different binning regimes. In one regime, the A-type (>15  $\mu\text{m}$ ), B-type (5–15  $\mu\text{m}$ ), and C-type (<5  $\mu\text{m}$ ) allowed a comparison through a commonly used method (Bechtel et al 1993; Zayes et al 1994; Wilson et al 2006). In the second regime, the binning of the granules was done in seven groups: >30  $\mu\text{m}$ , 20–30  $\mu\text{m}$ , 10–20  $\mu\text{m}$ , 5–10  $\mu\text{m}$ , 2–5  $\mu\text{m}$ , 1–2  $\mu\text{m}$ , and <1  $\mu\text{m}$ . This regime was developed for this work to determine whether binning in smaller groups would be useful for starch size distribution studies. The A-type granules in the spelt starch showed a significantly lower total volume % in all cultivars and years evaluated except Rouquin 1997, 1999 and Lobo

1997, which did not differ from the control (70.3%) (Table V). The B-type starch granules in spelt wheats all showed a greater volume % when compared with the control (26.8%), with the exception of Lobo 1997 at 25.8%. The C-type granules in spelt wheat also showed a significantly greater volume % over the RBS control (2.9%), with the exception of Oberkulmer Rotkorn 1999, Brute 1999, and Lobo 1997 (Table V).

If starch populations are segmented into seven groups then Oberkulmer Rotkorn 1999; Rouquin 1999; Brute 1999; and Lobo 1997 and 1999 show a significantly greater volume % in the largest granule group of >30  $\mu\text{m}$  compared with the RBS control (31.4%), while the remainder of the samples showed lower volume % in that group. Starch granules of 20–30  $\mu\text{m}$  were lower in volume % for all cultivars and years compared with the RBS control (32.7%). In addition, while the 10–20  $\mu\text{m}$  sizes were lower in all but two cultivars, Lobo 1999 and Sammy 1999 had a greater volume % than the RBS control (14.7%). The 5–10  $\mu\text{m}$  size group showed Oberkulmer Rotkorn 1997, 1998, 1999; Rouquin 1998; Brute 1997, 1998, 1999; Lobo 1998, 1999; and Sammy 1997, 1998, 1999 were higher than the RBS control (18.3%). Rouquin 1997, 1999 showed no significant difference and only Lobo 1997 was significantly lower in volume %. In the 2–5  $\mu\text{m}$  group only Lobo 1997 was not significantly different than the RBS control (2.9%). Oberkulmer Rotkorn 1999, Rouquin 1999, and Brute 1999 were lower than the control, and the remaining samples were significantly greater than the control (Table V).

Two correlation sets were calculated to evaluate how granule size distribution affects crumb scores, loaf volume, % amylose, and RVA pasting measurements. These correlations were pooled by cultivar over the three growing seasons and by growing season to all cultivars. Cultivar revealed no significant correlations of tested parameters to starch size distributions. If the cultivars were pooled and evaluated by year, some significant correlations are evident (Table VI). Crumb score showed a significant negative correlation ( $r = -0.660$ ,  $P = 0.05$ ) of >30  $\mu\text{m}$  group for 1997 but a positive correlation ( $r = 0.623$ ,  $P = 0.05$ ) for 1999. Crumb score also showed a positive correlation ( $r = 0.767$ ,  $P = 0.05$ ) for the 10–20  $\mu\text{m}$  group, B-type granules ( $r = 0.874$ ,  $P = 0.001$ ), and the C-type granules ( $r = 0.778$ ,  $P = 0.05$ ). A negative correlation for crumb score was shown in 1999 and A-type granules ( $r = -0.747$ ,  $P = 0.01$ ). Loaf volume showed a negative correlation for the >30  $\mu\text{m}$  group for 1997 ( $r = -0.909$ ,  $P = 0.001$ ) and then a positive correlation in 1999 to the B-type granules ( $r = 0.711$ ,  $P = 0.05$ ). % Amylose showed a positive correlation in 1999 to 10–20  $\mu\text{m}$

**TABLE III**  
Total and Damaged Starch in Spelt Wheat Flours and Amylose in the Starches<sup>a</sup>

Cultivar	Year	Total Starch (%)	Starch Damage (%)	Amylose (%)
Oberkulmer Rotkorn	1997	81.4a	3.2a*	30.8a*
	1998	72.4b*	3.2a*	30.4a*
	1999	74.1b*	3.0a*	30.6a*
Rouquin	1997	81.6a	2.7b*	33.2a*
	1998	77.7a	3.1a*	30.7a*
	1999	78.7a	3.2a*	30.7a*
Brute	1997	82.0a	2.8b*	33.2a*
	1998	75.6a	3.0b*	31.4ab*
	1999	79.9a	3.2a*	29.8b*
Lobo	1997	79.1a	2.6b*	32.0a*
	1998	76.9a	2.5b*	30.6a*
	1999	74.6a	3.0a*	32.0a*
Sammy	1997	79.6a	2.3b*	31.5a*
	1998	80.3a	2.1b*	31.1a*
	1999	80.6a	3.2a*	31.5a*
RBS		79.1	4.3	26.1

<sup>a</sup> Means in the same column followed by different letters indicate significant differences ( $P \leq 0.05$ ); \*, indicates a significant difference ( $P \leq 0.05$ ) from the control flour, a 1999 regional baking standard (RBS) obtained from the U.S. Grain Marketing Production Research Center, Manhattan, KS.

**TABLE IV**  
Thermal Properties of Spelt Starch at  $\approx 80\%$  MC<sup>a,b</sup>

Cultivar	Year	Gelatinization				Dissociation of Amylose/Lipid			
		$T_o$ (°C)	$T_p$ (°C)	$T_c$ (°C)	$\Delta H$ (J/g)	$T_o$ (°C)	$T_p$ (°C)	$T_c$ (°C)	$\Delta H$ (J/g)
Oberkulmer Rotkorn	1997	53.6a	63.3	72.8a	13.2a	86.8a*	98.6a*	103.9a*	1.6a
	1998	56.6a	63.9a	72.9a	8.2a	85.3ab*	96.6a*	103.5a*	1.4a
	1999	55.2a	63.2a	71.4a	11.8a	85.0b*	97.2a*	103.6a*	1.7a
Rouquin	1997	54.7b*	63.2a	72.0a	12.3a	86.9a*	98.0a	103.9a	1.6a
	1998	54.1b	62.0a	71.7a	11.4a	86.1a*	96.2a	103.3a	1.4a
	1999	56.3a	63.6a	72.2a	11.0a	85.1a	96.3a	102.3a	1.4a
Brute	1997	52.6b	62.1a	72.0a	11.2a	87.2a*	98.2a*	104.6a*	1.8a*
	1998	55.2a*	62.9a	71.8a	10.9a	83.5b	95.3b*	102.8b*	1.5b
	1999	54.7a*	63.2a	72.3a	11.6a	84.7ab	95.7b*	103.4ab*	1.7ab*
Lobo	1997	55.0b	63.0a	72.6a	12.5a	88.2a	97.5ab	103.5ab*	1.5a
	1998	54.9b	63.1a	72.4a	10.9a	88.0a	95.9b	103.0b*	1.6a
	1999	58.0a*	65.6a	75.7a	8.8a	88.9a	100.4a*	105.7a*	1.6a
Sammy	1997	56.1a*	63.3a	71.6a	10.4a	88.9a*	99.3a*	104.3a*	1.3a
	1998	56.6a*	63.0a	70.2a	8.9a	84.1c*	95.3b*	104.5a*	1.3a
	1999	56.2a*	63.7a	72.1a	9.5a	85.8b*	98.5a*	104.4a*	1.6a
RBS		52.8	62.9	71.6	10.9	82.9	93.7	100.5	1.5

<sup>a</sup>  $T_o$ ,  $T_p$ , and  $T_c$  = onset, peak, and complete temperature, respectively;  $\Delta H$  = enthalpy change. Data are averages of two replicates per sample.

<sup>b</sup> Means in the same column followed by different letters indicate significant differences ( $P \leq 0.05$ ); \*, indicates a significant difference ( $P \leq 0.05$ ) from the control flour, a 1999 regional baking standard (RBS) obtained from the U.S. Grain Marketing Production Research Center, Manhattan, KS.

group ( $r = 0.637$ ,  $P = 0.05$ ) and the C-type population of granules ( $r = 0.638$ ,  $P = 0.05$ ), which resulted in the expected negative correlation to the A-type granules ( $r = -0.699$ ,  $P = 0.05$ ).

### Swelling Power (SP)

The RBS control and three spelts (Sammy 1999, Brute 1999, and Lobo 1999) as well as a partial waxy (lower amylose) HRW wheat (Ike) were tested. Average SP at 95°C with 3.6% flour solids were RBS control (15.4 g/g), Sammy 1999 (16.1 g/g), Brute 1999 (17.3 g/g), Lobo 1999 (17.1 g/g), and Ike (22.3 g/g).

### Starch Pasting Properties

Peak viscosity of the isolated spelt starches was 192.2–239.7 RVU compared with the RBS control (188.2 RVU) (Table VII). The trough viscosity was 73.6–138.8 RVU compared with the RBS control (70.0 RVU). Final viscosity and setback (recovery of the viscosity during cooling of the heated starch suspension) were consistently higher at 161.2–297.1 and 87.2–161.8 RVU, respec-

tively, compared with the control (142.4 and 72.4 RVU). Peak time showed Oberkulmer Rotkorn 1997; Rouquin 1997; Brute 1997; Lobo 1997, 1999; and Sammy 1997, 1999 were all higher than the control (5.2 min). Oberkulmer Rotkorn 1997; Rouquin 1997; Brute 1997; Lobo 1997, 1998, 1999; and Sammy 1997 had pasting temperatures higher than the control (81.6°C), while Rouquin 1999 and Lobo 1998 were lower and the remainder of the samples showed no significant differences from the control (Table VII).

Year 1997 consistently had the highest final viscosity, setback, and trough of the three years studied. RVA final pasting viscosity showed correlations (Table VI) in 1999 with significant positive correlations in the 10–20  $\mu\text{m}$  group ( $r = 0.994$ ,  $P = 0.001$ ), B-type population ( $r = 0.932$ ,  $P = 0.001$ ), and C-type population ( $r = 0.995$ ,  $P = 0.001$ ), but showed a negative correlation to the A-type population ( $r = -0.954$ ,  $P = 0.001$ ). RVA pasting temperature showed correlations in 1998 with significant positive correlations in the 10–20  $\mu\text{m}$  group ( $r = 0.604$ ,  $P = 0.05$ ), the B-type popula-

TABLE V  
Granule Size Distributions (vol %) of Spelt Wheat Starches<sup>a</sup>

Cultivar	Year	>30 $\mu\text{m}$	20–30 $\mu\text{m}$	10–20 $\mu\text{m}$	5–10 $\mu\text{m}$	2–5 $\mu\text{m}$	1–2 $\mu\text{m}$	<1 $\mu\text{m}$	A-Type >15 $\mu\text{m}$	B-Type 5–15 $\mu\text{m}$	C-Type <5 $\mu\text{m}$
Oberkulmer Rotkorn	1997	30.4b*	21.00a*	20.9b*	24.4b*	3.3b*	0.1a	0.0a	58.0a*	38.7a*	3.0b*
	1998	15.5c	22.1a*	23.5a*	34.8a*	4.0a*	0.1a	0.0a	44.8b*	51.1b*	4.1a*
	1999	34.2a*	19.1b*	20.3c*	23.9b*	2.4c*	0.1a	0.1a	58.8a*	38.6a*	2.5c*
Rouquin	1997	33.8b	25.4a*	18.7b*	19.0b	3.2b*	0.1a	0.0a	65.8a*	31.4b	3.2b*
	1998	24.4c*	26.4a*	21.0a*	24.1a*	4.2a*	0.1a	0.0a	58.6b*	37.2a*	4.2a*
	1999	39.3a*	23.8a*	16.6c*	17.9b	2.4c*	0.1a	0.0a	68.6a	29.1b	2.4c*
Brute	1997	29.7b*	16.8c*	21.3a*	28.4a*	3.8a*	0.0c*	0.0a	52.2c*	44.1a*	3.8a*
	1998	28.3c*	25.9a*	18.9b*	23.3b*	3.4b*	0.1a*	0.0a	60.6b*	35.9b*	3.6b*
	1999	38.9a*	21.5b*	17.2c*	19.7c*	2.7c*	0.1b*	0.0a	65.8a*	31.5c*	2.7c*
Lobo	1997	37.8a*	27.8a*	16.0b*	15.8c*	2.5c	0.1a	0.0a	71.6a	25.8c	2.6c*
	1998	25.8b	23.6b*	21.5a*	25.5b*	3.5b*	0.1a	0.0a	56.4b*	40.0b*	3.6b*
	1999	35.1a*	8.9c*	12.2c*	36.9a*	6.7a*	0.1a	0.0a	46.1c*	47.0a*	6.8a*
Sammy	1997	24.9b*	24.0a*	23.1a*	24.2c*	3.7b*	0.1a	0.1a	56.7a*	39.4b*	3.9b*
	1998	25.1ab*	23.5a*	21.5b*	26.2b*	3.7b*	0.1a	0.0a	55.6a*	40.6b*	3.8b*
	1999	26.7a*	8.7b*	12.9c*	44.4a*	7.3a*	0.1a	0.0a	37.7b*	55.0a*	7.4a*
RBS		31.4 $\pm$ 0.13	32.7 $\pm$ 0.05	14.7 $\pm$ 0.05	18.3 $\pm$ 0.09	2.9 $\pm$ 0.05	0.1 $\pm$ 0.00	0.0	70.3 $\pm$ 0.17	26.8 $\pm$ 0.13	2.9 $\pm$ 0.05

<sup>a</sup> Means in the same column followed by different letters indicate significant differences ( $P \leq 0.05$ ); \*, indicates a significant difference ( $P \leq 0.05$ ) from the control flour, a 1999 regional baking standard (RBS) obtained from the U.S. Grain Marketing Production Research Center, Manhattan, KS.

TABLE VI  
Pearson Correlation Coefficients for Baking and Pasting Characteristics vs. Granule Size  
Volume % Distribution for 3 Years of Five Spelt Wheat Starches<sup>a</sup>

Parameter and Year	Starch Size Distribution (vol %)				
	>30 $\mu\text{m}$	10–20 $\mu\text{m}$	Type A (>15 $\mu\text{m}$ )	Type B (5–15 $\mu\text{m}$ )	Type C (<5 $\mu\text{m}$ )
Crumb					
1997	<b>-0.660*</b>	-0.398	0.295	-0.280	-0.461
1998	0.145	-0.140	-0.365	0.378	-0.042
1999	<b>0.623*</b>	<b>0.767*</b>	<b>-0.746**</b>	<b>0.874***</b>	<b>0.778*</b>
Loaf volume					
1997	<b>-0.909***</b>	0.005	0.295	-0.280	-0.461
1998	0.105	-0.369	-0.300	0.325	-0.280
1999	<b>0.711*</b>	0.378	-0.584	<b>0.623*</b>	0.390
% Amylose					
1997	-0.437	0.122	-0.034	0.031	0.063
1998	-0.100	-0.198	0.556	-0.557	-0.237
1999	0.250	<b>0.637*</b>	<b>-0.699*</b>	0.577	<b>0.638*</b>
Final pasting viscosity					
1997	0.064	-0.274	0.335	-0.343	-0.265
1998	0.270	-0.205	-0.360	0.377	-0.113
1999	0.224	<b>0.994***</b>	<b>-0.954***</b>	<b>0.932***</b>	<b>0.995***</b>
Pasting temperature					
1997	0.311	0.111	-0.252	0.257	0.155
1998	-0.303	<b>0.604*</b>	<b>-0.752**</b>	<b>0.738**</b>	0.552
1999	0.120	0.302	-0.332	0.344	0.306

<sup>a</sup> \*, \*\*, \*\*\*, Significant at  $P < 0.05$ ,  $P < 0.01$ , and  $P < 0.001$ , respectively. Values in bold indicate significant differences.

tion ( $r = 0.738$ ,  $P = 0.001$ ), and a negative correlation to the A-type population ( $r = -0.752$ ,  $P = 0.001$ ).

## DISCUSSION

Thousand kernel weights of these spelt samples seem low when compared with a previous study done with Oberkulmer Rotkorn, and Rouquin grown in Europe (Marconi et al 1999). In Europe, the 1,000 kernel weights were 49–55 g, while the same two samples grown in Ohio were 26–41 g (Table I). This difference may be caused by the diversity of the two environments. The flour milling yields of all dehulled spelt cultivars and years were uniformly high (63–72%) and comparable to those of HRS and HRW wheat in previous studies (Abdel-Aal et al 1997). The degree of damaged starch in spelt flour was low in all cultivars and growing seasons because of kernel softness (Tables II and IV). Total starch levels in spelt flour were similar to the RBS control ( $\approx 80\%$ ).

Amylose levels in starch were elevated to 30–33% with the RBS control at 26% (Table III). These amylose contents contradict a study done by Abdel-Aal et al (1999a) which reported soft spelt amylose at  $\approx 22\%$  using the same Megazyme Con-A precipitation method as used in this study. The cultivars for that study were not the same and were adapted for growing in Western Canada. During the Con-A assay procedure, amylose must not be allowed to retrograde after removal of the amylopectin-lectin complex, otherwise amylose levels will be in error to the low side. Some studies have reported amylose content higher in large wheat starch granules (Kulp 1973; Duffus and Murdoch 1979; Soulaka and Morrison 1985; Morrison 1989). Others reported the same amylose content in both small and large granules (Bathgate and Palmer 1972; Evers et al 1974). A study using 12 soft wheat cultivars showed a positive correlation between increase in amylose content and an increase in volume % of 9.9–18.5  $\mu\text{m}$  granules (Raeker et al 1998). This is consistent with our results of a positive correlation between amylose content and the 10–20  $\mu\text{m}$  groups in growing year 1999 (Table VI).

The hot-water swelling power (SP) test is a relatively simple test as it can be done with whole meal or flour because starch levels between most samples are similar, thus the time involved in isolating starch is eliminated. The SP of starch was reported to be inhibited by increased levels of amylose and lipid (Tester and Morrison 1990, 1992; Morrison et al 1993; Wang and Seib 1996) so it was used in this study to confirm the higher levels of amylose found in spelt wheat. The RBS control, three spelts (Sammy 1999; Brute 1999; and Lobo 1999) as well as a partial waxy (lower amylose) HRW wheat (Ike) were tested.

Average SP at 95°C with 3.6% flour solids were RBS control (15.4 g/g), Sammy 1999 (16.1 g/g), Brute 1999 (17.3 g/g), Lobo 1999 (17.1 g/g), and Ike (22.3 g/g). The Ike flour, which contains 4–5% less amylose than flour from normal wheats, showed the expected increase in SP compared with the RBS control (Seib et al 2000). However, the spelt wheats in this study with amylose content at least 4% higher than the RBS control showed a slightly higher SP, rather than the expected lower SP. Decreased starch lipid content as well as a higher proportion of long chains in amylopectin are also correlated to an increase in the SP (Sasaki and Matsuki 1998). Those variables were not determined in this study and they may counteract the effects of increased amylose.

All starches in this study showed the typical DSC thermograms for nonwaxy cereal starches (Akashi et al 1999). The DSC curves showed a large endothermic peak between  $\approx 53$  and  $73^\circ\text{C}$  and a higher temperature peak between  $\approx 83$  and  $103^\circ\text{C}$  (Table IV). These peaks were assigned to the gelatinization of amylopectin and the dissociation of the amylose/lipid complex, respectively (Eliasson 1994). No trend of difference could be discerned for the first peak (gelatinization) between the spelt starches and the control, with the exception of some minor shifts in  $T_o$  (Table IV). An increase in  $T_o$ ,  $T_p$ , and  $T_c$  for dissociation of the amylose/lipid complex in a spelt starch over the control (Table IV) was noted for some of the cultivars-years tested. Although not statistically significant for all samples tested, this follows a trend of the spelt starch having increased amylose and a larger population of C-type starch granules compared with the HRW control (Table V). As this transition is due to the amylose/lipid complex, the greater  $T_o$ ,  $T_p$ , and  $T_c$  temperatures could be explained by a greater lipid content found in small C-type granules (Eliasson and Karlsson 1983).

RVA profiles varied more within cultivars than year to year. Starches from growing year 1997 consistently showed the highest pasting curves compared with 1998 and 1999 (Table VII). All spelt starch samples gave pasting peaks and final viscosities consistently higher than the RBS control. Residual levels of  $\alpha$ -amylase can affect pasting profiles in isolated starches. Testing of the 1997 isolated starch samples using the Ceralpha method, which is very sensitive to  $\alpha$ -amylase activity with a detection limit of 0.01 mU/mL (McCleary and Sheehan 1987), showed no activity (data not shown). One unit of  $\alpha$ -amylase activity is defined as the amount of enzyme that releases 1  $\mu\text{mol}$  of *p*-nitrophenol/min under assay conditions from the end blocked,  $\alpha$  *p*-nitrophenyl maltoheptoside (McCleary and Sheehan 1987).

One possible explanation for the difference in RVA curves is that particle size can have an effect on pasting profiles done at 12% starch solids (Sasaki et al 2000). Work done on maize starch

TABLE VII  
Pasting Properties (RVU) of Isolated Spelt Starches<sup>a</sup>

Cultivar	Year	Peak 1	Trough 1	Breakdown	Final Viscosity	Setback	Peak Time (min)	Pasting Peak ( $^\circ\text{C}$ )
Oberkulmer Rotkorn	1997	208.3a*	105.0a*	103.2c*	255.4a*	150.4a*	5.6a*	84.5a*
	1998	199.7b*	76.3b*	123.5a*	208.5b*	132.3b*	4.9c*	81.6b
	1999	192.2c*	73.6c*	119.5b	164.0c*	91.4c*	5.2b	80.8b
Rouquin	1997	217.4a*	116.3a*	100.1c*	275.0a*	158.7a*	5.7a*	81.2b
	1998	221.4a*	77.3b*	144.1a*	164.9b*	87.6b*	5.1c*	80.8ab
	1999	197.4b*	74.0c*	123.4b*	161.2b*	87.2b*	5.2b	77.1b*
Brute	1997	224.3a*	123.0a*	101.3c*	284.8a*	161.8a*	5.8a*	83.6a*
	1998	219.4b*	84.8b*	135.0a*	208.2b*	123.4b*	5.1b	80.0b
	1999	194.4c*	74.9c*	119.5b	163.9c*	89.00c*	5.2b	80.0b
Lobo	1997	239.7a*	138.8a*	100.9c*	297.1a*	158.3a*	5.9a*	84.4a*
	1998	212.0b*	77.4c*	134.6a*	176.7c*	99.3c*	5.1c	80.8c*
	1999	201.0c*	86.0b*	115.0b	196.3b*	110.3b*	5.5b*	82.5b*
Sammy	1997	229.0a*	136.4a*	92.6b*	286.5a*	150.08a*	5.8a*	85.2a*
	1998	220.3b*	76.7c*	143.6a*	165.8c*	89.13c*	5.0c*	80.0b
	1999	196.9a*	93.8b*	103.2b*	200.3b*	106.5b*	5.3b*	79.1b
RBS		188.2	70.0	118.2	142.4	72.4	5.2	81.6

<sup>a</sup> Means in the same column followed by different letters indicate significant differences ( $P \leq 0.05$ ); \*, indicates a significant difference ( $P \leq 0.05$ ) from the control flour, a 1999 regional baking standard (RBS) obtained from the U.S. Grain Marketing Production Research Center, Manhattan, KS.

revealed the relative size of the peaks, the final shape of the peak, and the shape of curve depended on the size fraction of the material (Becker et al 2001). Their work also revealed that the greater the particle size, the higher the final pasting viscosity. RVA pasting requires the starch to be finely dispersed in water during the test. Air-drying of starch is usually done after isolation, and often the starch dries to form hard clumps or coagulated flakes that must be reground before RVA analysis. The adhesive on the granule surface is most likely residual protein or pentosans. In this study, air-dried samples were ground in a round-bottom 100-mL centrifuge tube with a plastic pestle, followed by rubbing through a 0.25-mm wire-mesh sieve screen. If this particle-size reduction is not consistent, variations in the profiles may be apparent. This shearing process could also lead to additional starch damage in the isolated starches. Starch damage may also have an effect on pasting profiles, increasing the pasting peak and final viscosities with increased starch damage (Grant 1998).

While starch damage was performed on the flour with resultant low values reflecting the soft character of these cultivars (Table I), starch damage was not evaluated again on the air-dried, isolated starch. Others have reported that air-dried, freeze-dried samples showed significant differences in the amount of starch damage due to the amount of grinding necessary on the air-dried sample to match the low bulk density of the freeze-dried sample (Grant 1998). The air-dried starches had greater water-binding capacity at 25°C as a result of higher starch damage and showed higher RVA peak viscosities than freeze-dried samples. However, this does not explain why RVA profiles of the spelt starch were consistently higher than the RBS control. Starch damage should be measured after starch isolation, rather than before, in flour.

Starch size distributions showed some significant correlations to RVA final pasting viscosity in 1999 and pasting temperature in 1998 (Table VI). In 1999, the 10–20  $\mu\text{m}$  group, B-type and C-type showed a positive correlation to final pasting viscosity. The A-type population resulted in a strong negative correlation for that year. Pasting temperature showed the same trend in 1998. The 10–20  $\mu\text{m}$  and the B-type populations of starch granules resulted in a positive correlation to pasting temperature and A-type population resulted in a negative correlation. Even though the isolated spelt starches in this study had relatively consistent levels of amylose in all cultivars (Table III), it does not explain the variability of peak paste viscosity and final past viscosity within each cultivar (Table VII).

It is believed that starch lipids, rather than amylose, may be primarily responsible for the different swelling tendencies of wheat A and B-type starch granules (Tester and Morrison 1990) but they do not completely account for all starch pasting differences (Shinde et al 2003). Starch lipids were not measured in the present study. Various wheat starch size fractions differ considerably in terms of size, specific surface area, and swelling capacity (Soulaka and Morrison 1985; Tester and Morrison 1990; Fortuna et al 2000). B- and C-type granules, which are smaller in size, have larger specific surface areas compared with the A-type granules. Thus, at equal weights, the B- and C-type granules would be expected to possess a denser packing ability and occupy a relatively smaller volume compared with the A-type granules. Most starch rheological behavior is influenced by particle size; in dilute suspensions, large-sized particles tend to be more viscous compared with those of smaller size (Wong and Lelievre 1981, 1982), even at identical concentrations. Thus, starch suspensions with  $\leq 10\%$  solids and high proportions of A-type granules would be expected to exhibit higher viscosity than starch suspensions with high contents of B-type granules when compared on an equal basis (Shinde et al 2003). The relationships between granule type and starch pasting characteristics might suggest that granule size itself provides significant contribution to wheat starch pasting properties, although additional chemical and physical differences such as the amylopectin chain-length and distribution could also

account for the different pasting properties of these starches. In recent work by Franco et al (2002), they showed that increasing average chain length of amylopectin in soft wheat cultivars increased gelatinization temperature and paste peak viscosity and shear thinning. Those results substantiate the view of Panozzo and Eagles (1998) that amylose content may not be the sole determinant of pasting viscosity.

The rigidity of swollen granules has also been linked to starch paste consistency. It is not known whether differences in stiffness of the A-, B-, and C-type swollen granules or granule remnants might offer additional explanation for wheat starch pasting behavior (Eliasson and Bohlin 1982; Ring 1985; Steeneken 1989). While lipid and amylose play a significant role in starch pasting behavior, the variability of the starch pasting behavior may be influenced considerably by A-, B-, and C-type granule ratios and could offer both cultivar-based and environment-based fluctuations in starch pasting behavior (Shinde et al 2003).

Protein content of the spelt flour was consistently higher in all cultivars grown in 1997 (Table II). Gluten strength of the protein remained rather weak for the majority of samples evaluated as evidenced by the rather short mix times of all but Rouquin 1999 and Brute 1999 with mix times of 6.6 and 11.00 min, respectively. Bake tests with 10 g of sample were used due to the limited amount of sample on hand. Prior work showed that both crumb scores and loaf volumes of micro-loaves correlated well with those from the standard 100-g bake tests in common wheats (Shogren and Finney 1984). In the work here on spelt wheats, high loaf volumes correlated well with high protein content, especially in 1997. Another factor that likely improved the loaf volume of these relatively weak gluten spelts was the oxidizing effect of L-ascorbic acid in the bread formulation. Abdel-Aal et al (1999) found ascorbic acid levels of 50–200 ppm increased loaf volumes by  $>21\%$  when compared with nontreated spelt flour.

Loaf volume showed a negative correlation to  $>30 \mu\text{m}$  volume % starch size distribution in 1997, then showed a positive correlation to this group in 1999, as well as the B-type population in 1999 (Table VI). This supports the conclusions of Soulaka and Morrison (1985) that the percentage of B-type granules in the starch has an appreciable effect on loaf volume. Stoddard (1999) reported that the higher surface-to-volume ratio of the B-type granules has been associated with a higher rate of water absorption than that of the A-type granules, affecting the mixing of the dough and baking properties such as loaf volume and crumb score.

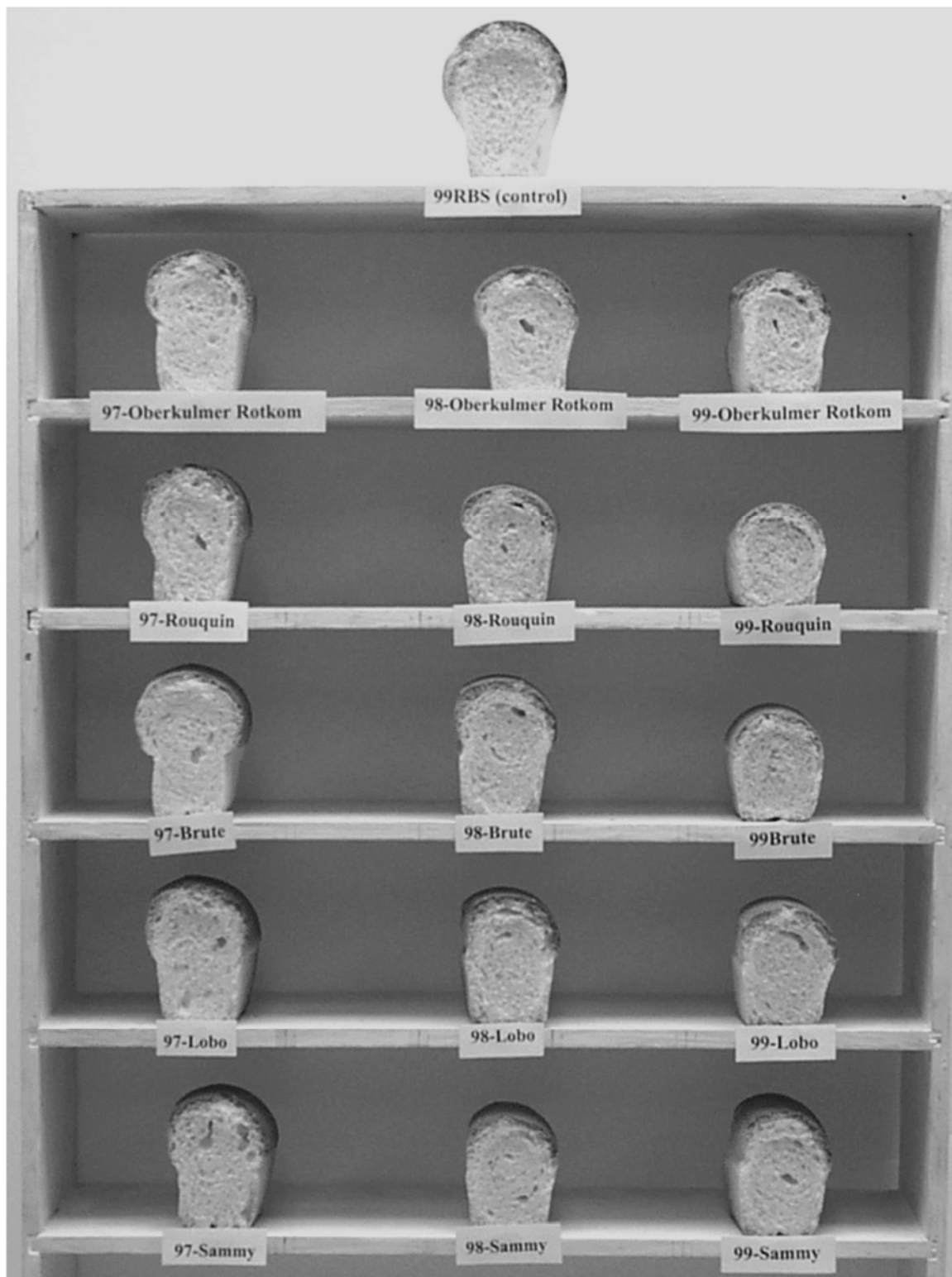
The reports on the effects of starch granule size on bread baking performance in the literature are contradictory. Hosney et al (1971) found small starch granules had the same breadmaking characteristics as that of normal starch. Similarly, D'Appolonia and Gilles (1971) reported the same loaf volumes were obtained for breads baked with gluten-starch blends containing either small or large starch granules. When coarse, medium, and fine starch granule preparations were used in baking experiments, no clear effects of the starch fractions on proof time, water absorption, or bread volume were observed (Lelievre et al 1987). On the other hand, Kulp (1973) concluded that small granules have a lower baking volume potential than corresponding normal starch. Most of these investigations of the effects of starch properties on baking performance reported in the literature were done on whole populations of starch granules on relatively crude starch fractions, which may account for why different baking results were reported (Sahlstrom et al 1998). In addition, there has been no consistency in methods of measuring granule size distributions and baking performance.

The gas cells in dough coalesce as temperature rises during the early stages of baking, and starch granules, with different temperatures of gelatinization and swelling properties, play a crucial role in the expansion of the loaf (Kusunose et al 1999). Due to the unique properties of the different size starch granules in wheat, it

is reasonable to consider starch size distribution as having a significant impact on baking performance.

Crumb scores also correlated well with higher protein content, with all the 1997 cultivars, with the exception of Sammy 1997 scoring close to the HRW control RBS (4.25 out of 5.00) (Table II). While this scoring is a subjective evaluation done by the lead baker, a photograph of one replicate of the first bake was included to show loaf volume and crumb grain (Fig. 1). Significant nega-

tive correlations to crumb score were also noted for starch size distribution in  $>30\ \mu\text{m}$  group in 1997 and a positive correlation in 1999 (Table VI). This follows the correlations attained with loaf volume. No explanations can be offered for this reversal. Other positive correlations to crumb score versus size distribution in 1999 was 10–20  $\mu\text{m}$  B-type and C-type populations, indicating the smaller size granules may be more important to crumb grain. In 1999, the A-type population showed a negative correlation to



**Fig. 1.** Microbake loaves (10 g) of five spelt cultivars from three years. This is one of two replicates performed on this group of spelt flours. RBS, Regional Baking Standard control.



crumb score, which seems to contradict the positive correlation of the >30  $\mu\text{m}$  group. This may be due to the significant binning differences within the two groups.

The generalizations presented in this discussion concerning spelt wheat starches need to be verified with more in-depth investigations, including the chemical and physical properties. The limited data presented here on spelt wheat starch indicates it is similar to other wheat starches, although environment seems to play a critical role.

## CONCLUSIONS

Spelt wheat gave adequate flour in all cultivars and years tested, however gluten strength and bake loaf volume were at least  $\approx 10$ –15% lower when compared with a HRW control. The spelt loaves with 10–15% lower volume produced good crumb scores and had a creamy color. Amylose content was significantly elevated in all spelt cultivars and years tested. If the cultivars were pooled into year grown, significant positive correlations were realized between B- and C-type granule populations and amylose content, final pasting viscosity, and pasting temperature of starch, as well as loaf volume and crumb score. Negative correlations were noted for the large A-type granules to amylose level, final pasting viscosity, final pasting viscosity, and pasting temperature of starch as well as crumb score. In the 15 spelt samples examined in this study, growing year seemed to be the determining factor in these correlations, not cultivar. Consequently, environment plays a critical role in spelt wheat development, as is the case in most cereals. Results of this work also support the importance of starch size distribution as a critical component in the study of wheat quality.

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